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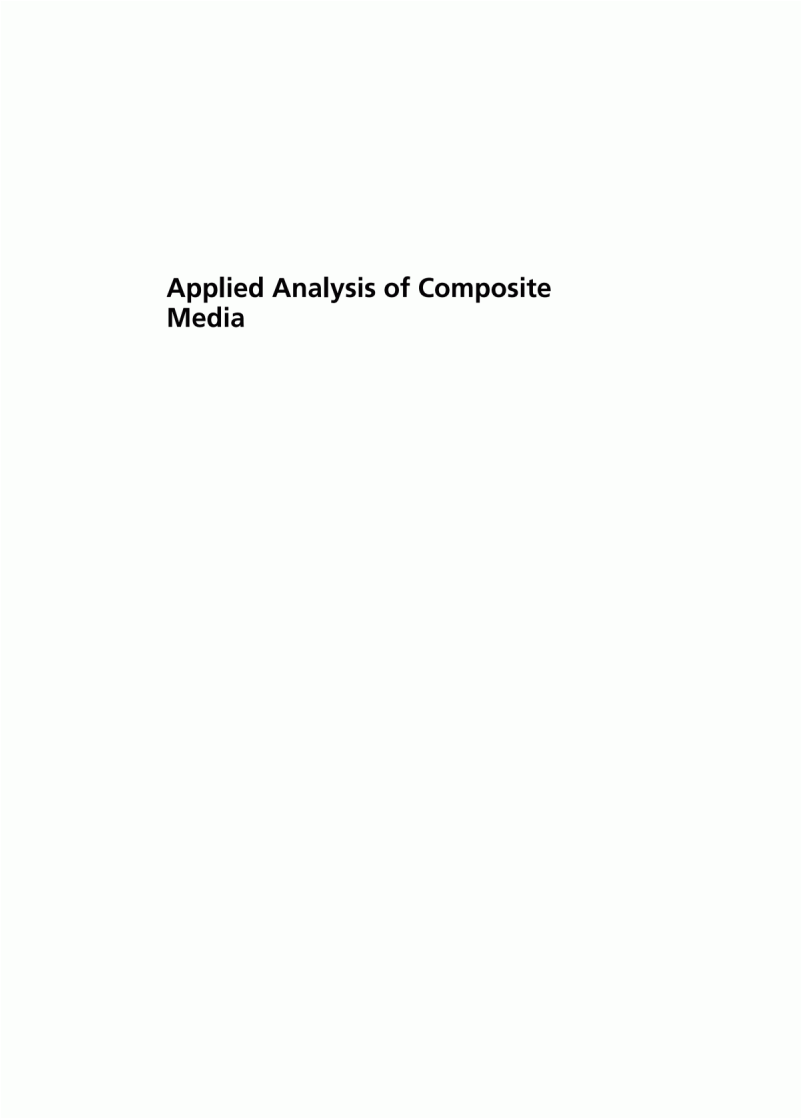

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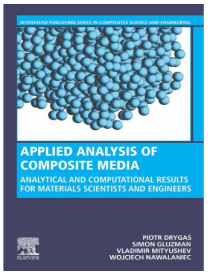

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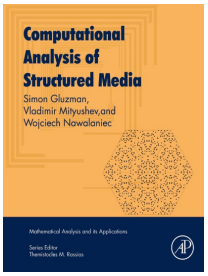

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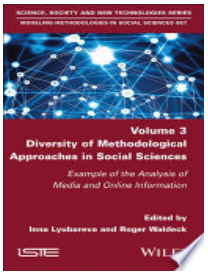
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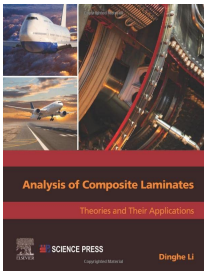

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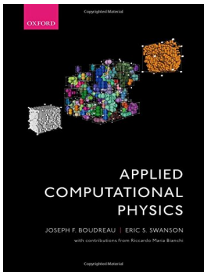

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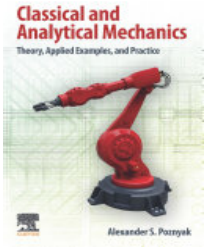

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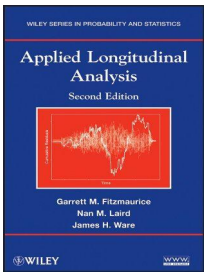

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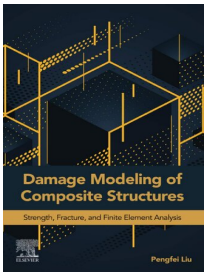

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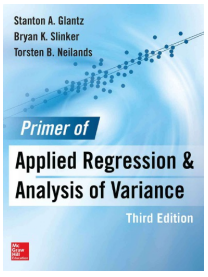

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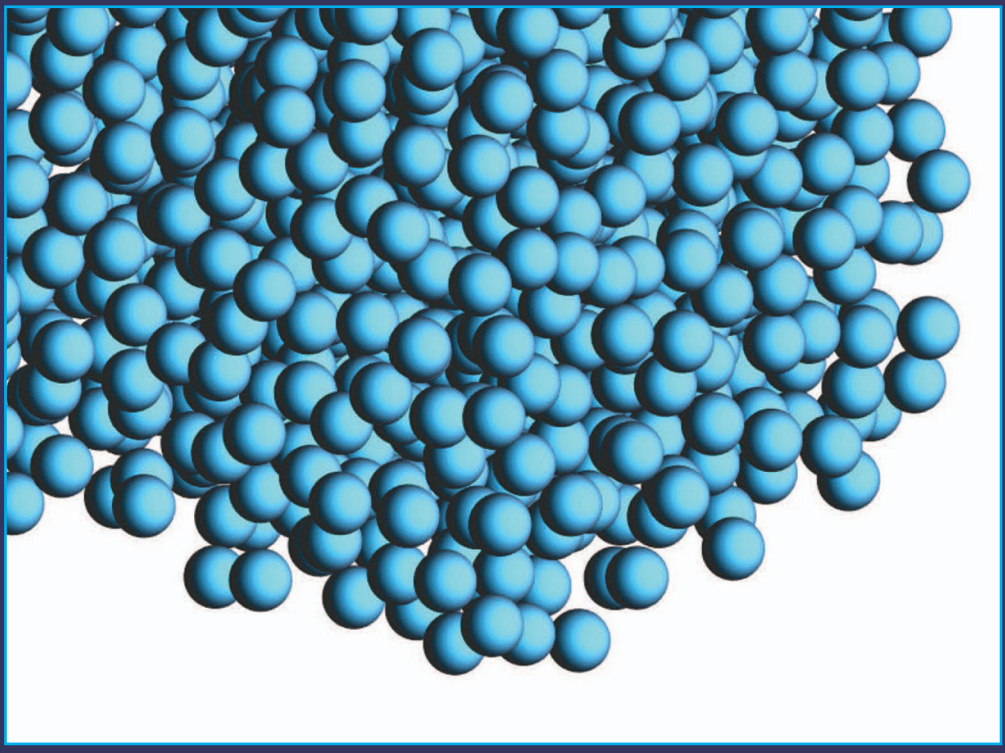

APPLIED ANALYSIS OF COMPOSITE MEDIA

ANALYTICAL AND COMPUTATIONAL RESULTS FOR MATERIALS SCIENTISTS AND ENGINEERS

PIOTR DRYGAŚ
SIMON GLUZMAN
VLADIMIR MITYUSHEV
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Applied Analysis of Composite Media

Analytical and Computational Results for Materials Scientists and Engineers

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To those who “live not by bread alone”

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Biography

The authors belong to the research scientific group www.materialica.plus

Piotr Drygaś, is Assistant Professor at the Faculty of Mathematics and Natural Sciences at the University of Rzeszow. He is interested in Boundary Value Problems, describing conductivity of fibrous composites with non ideal contact, and 2D elastic composites of random structure with ideal contact between matrix and inclusions.

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Vladimir Mityushev is Professor at the Institute of Computer Science of the Pedagogical University of Kraków, Poland. His academic and scientific activity is based on interdisciplinary international research devoted to applied mathematics and computer simulations. His main mathematical result is complete solution to the scalar Riemann–Hilbert problem for an arbitrary multiply connected domain. This result includes, for instance, the Schwarz–Christoffel mapping of multiply connected domains bounded by polygons onto circular domains, Poincaré series for the classical Schottky groups and other objects of the classical complex analysis constructed in other works in particular cases. The main scientific achievements of the group headed by VM concern application of the Riemann–Hilbert problem and of the generalized alternating method of Schwarz to 2D random composites and porous media, analytical formulas for the effective properties of regular and random composites, a constructive theory of RVE, pattern formation, and the collective behavior of bacteria. The developed approach revises the known analytical formulas and precisely answers the question how to determine macroscopic properties of random media.

Wojciech Nawalaniec is Assistant Professor at the Institute of Computer Science of the Pedagogical University of Kraków, Poland. WN is interested in simulation, classification and analysis of random structures. Also interested in application of symbolic-numerical calculations and machine learning to computational materials science. WN also develops algorithms and software modules providing solutions to scientific problems tackled by the Materialica+ Research Group.

Preface

In words of Sergei Prokofiev we define neoclassicism: "I thought that if Haydn were alive today he would compose just as he did before, but at the same time would include something new in his manner of composition. It seemed to me that had Haydn lived to our day he would have retained his own style while accepting something of the new at the same time. That was the kind of symphony I wanted to write, a symphony in classical style."

Classical theory of composites amounts to the celebrated Maxwell formula, also known as Clausius–Mossotti approximation. Actually, all modern self-consistent methods (SCM) perform elaborated variations on the theme, and are justified rigorously only for dilute composites when interactions among inclusions are neglected. In the same time, exact and high-order formulas for special regular composites which go beyond SCM were derived.

Let matrix conductivity be normalized to unity and σ denote the conductivity of inclusions. Introduce the contrast parameter $\varrho = \frac{\sigma-1}{\sigma+1}$. For many years it was thought that Maxwell's and Clausius–Mossotti approximation for the effective conductivity of 2D (3D) composites

$$\sigma_e = \frac{1+\varrho f}{1-\varrho f} + O(f^2) \tag{1}$$

can be systematically and rigorously extended to higher orders in f by taking into account interactions between pairs of spheres, triplets of spheres, and so on. However, it was recently demonstrated (Gluzman et al., 2017, Mityushev et al., 2018b, Mityushev, 2018) that the field around a finite cluster of inclusions can yield a correct formula for the effective conductivity only for non-interacting clusters. Rigorous justification of this fact is given in Appendix A.4 of the present book, based on the paper (Mityushev, 2018). The higher order term(s) can be properly found only after a subtle study of the conditionally convergent series.

The hard experimental evidence accumulated by material scientists and engineers begs for a constructive theory of random composites with explicit account for the geometry. The geometry is, de facto, another important *structural parameter*. As discussed in Nielsen (2005), "In itself the large number of completely different empirical stiffness expressions suggested for porous materials clearly indicates a need for a more rational research on composite properties versus composite geometry... Change of geometry will influence any mechanical/physical behavior of composites. Stiffness and viscoelasticity (creep and relaxation) will change. Shrinkage and eigenstress-strain (such as hydro-thermal properties, and heat conductivity are other examples of materials behavior, which will change with geometry. In order to cope rationally with

such changes in composite analysis we must increase our freedom to choose other analytical models than the specific, non-variable ones most often used to day." Our new book is dedicated mainly to constructive topics of boundary value problems and their applications to macroscopic properties of composites and of porous media. Symbolic-numerical computations are widely used to deduce new formulas important for engineers and researchers. New formulas for the effective properties are deduced in the form customized for engineering applications.

The outline of typical exposition is given below for the case of 2D elastic composites. Composites with non-overlapping circular inclusions randomly embedded in matrix are investigated. Special attention is paid to critical regimes related to the optimal packing of inclusions and to extreme physical constants (rigid and soft inclusions). Investigation of regular and random structures is based on the general approach of the RVE (representative volume element) and the corresponding structural sums. The proposed method yields an effective algorithm in symbolic-numeric form to compute structural sums as discrete multiple convolutions. In this book, new algorithms are described systematically, codes or pseudo-codes are given, and complexity of computations is studied.

We present also modified averaging computational method applied to the local stresses and deformations. Properly constructed series are reduced to polynomials and rational functions depending on the concentration of inclusions f. But it is not a final solution to the problem. Furthermore, these functions are replaced by asymptotically equivalent expressions. Special methods of resummation suggested in the book and in (Gluzman et al., 2017), bring accurate and compact formulas for all concentrations. Accurate analytical formulas for deterministic and random composites and porous media can be derived employing approximants, when the low-concentration series are supplemented with information on the high-concentration regime. Typical problems we encounter are characterized by asymptotic power laws.

Our first book (Gluzman et al., 2017) may be considered as an neoclassical answer to the question associated to Fig. 0.1, why does James Bond prefer shaken, not stirred martini with ice? Highly accurate computational analysis of structural media allowed us to explain the difference between various types of random composite structures. It is strongly related to the critical exponent s in the asymptotic behavior of the effective conductivity. In the limiting case of a perfectly conducting inclusions, the effective conductivity σ_e is expected to tend to infinity as a power-law, as the concentration of inclusions f tends to $f_c = \frac{\pi}{\sqrt{12}}$, the maximal value in 2D

$$\sigma_e(f) \sim (f_c - f)^{-\mathsf{s}}. \tag{2}$$

The dependence of the index s on the shaken-stirred regime of inclusions is displayed in Fig. 0.1. Similarly, one can consider different effective properties. Universality of the mathematical modeling implies that the same equations hold for the electric and thermal conductivity, magnetic permeability, anti-plane elastic strains and so on.

Scientific classicists are perpetually in search of universal answers to all questions concerning the transport properties of composite materials, which can be simply adjusted to any concrete case. Neoclassical approach includes their classical results as a

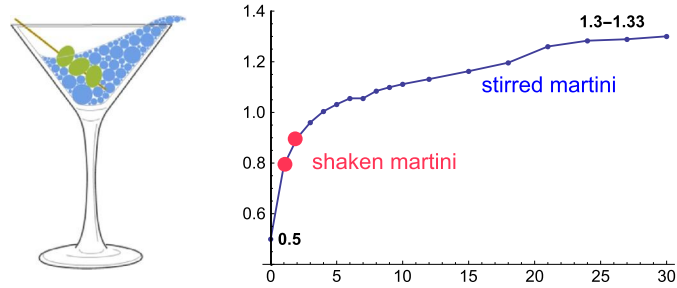

Figure 0.1 Why did James Bond prefer shaken, not stirred martini with ice? Because he sensed in martini the critical exponent s from formula (2). The dependence of s on the degree of disorder measured in steps of random walk is displayed in the graphics.

limit-case, complements it with another limit case of high-concentration percolating inclusions, but does not stop here. The problem now is getting shifted towards methodology (tool-box), concerned with properly matching the limit-cases. On the way one should develop a non-universal, structure-dependent expansions, as well as special approximation methods. From the warm and cosy world where universal answers exist, we are getting to the cold, unfriendly one. In such world each and every problem of the theory of composites should be studied in terms of the particular numerical set of structural sums, the particular large f limit found, and the particular approximation method carefully selected to receive formula for all f.

We are convinced that to derive a new formula, valid in the whole range of relevant variables, is not merely a mathematical exercise, or even a matter of convenience. It provides a fresh insight, since in the majority of cases realistic material sciences problems correspond neither to weak coupling (or low concentration) regime nor to strong coupling (high concentration) limit, but to the intermediate range of parameters. Such regime can be covered by some rather complex formula deduced from asymptotic regimes. It is quite handy for a scientist to possess a general mathematical toolbox to derive asymptotic, typically power laws, as well as explicit crossover formulas for a multitude of processes. Problems discussed in the book can be viewed as asymptotically classical, but in each of them, a neoclassical twist is supposed to make them more agreeable to the modern listener. Besides, they are all interesting and hold a promise in days to come.

Some authors equate an *approximate analytical formula* with a *model*. Such an approach is misleading, since a mathematical modeling involves fundamental governing equations, complemented by interface and boundary conditions. Different approximate formulas/solutions for the mathematical model hold under restrictions usually not discussed by authors. A serious methodological mistake may follow when intermediate manipulations are valid only within the precision $O(f)$, while the final formula is claimed to work with a higher precision, see an explicit example in Appendix A.4. In particular, it follows from our investigations that it is impossible to write a universal higher order formula independent on locations of inclusions. Such a universal formula holds only for a limited class of composites with non-interacting

inclusions, e.g., for dilute composites and the Hashin-Shtrikman coated sphere assemblage (Cherkaev, 2009).

Since Einstein, the transport coefficients in random and regular media are expressed as expansions in concentration f. Nevertheless, despite persistent efforts of such outstanding researchers as Batchelor, Bergman, Brady, Jeffrey, Milton, McPhedran, Torquato, Wajnryb the problem still exists of finding correct numerical coefficients in expansions. Besides, the validity of such short series is very limited, and their true value is still remains to be seen.

Let us address the Hashin–Shtrikman bounds and their extensions (Milton, 2002). The dependence of the effective conductivity of a random composite on f corresponds to some monotonous curve, drawn between the bounds. Such a curve can be sketched arbitrarily, and it will correspond to some unspecified distribution of inclusions. Often, we deal with a uniform distribution corresponding to a stir-casting process described by the random sequential addition (RSA) model (Kurtyka and Rylko, 2013, 2017). Thence main theoretical requirement to the geometric model consists not only in writing a formula, but in a precise description of the geometrical conditions imposed on deterministic or random locations of inclusions. The rigorous statement and study of this theoretical problem is necessary for the proper approach to various applied problems, e.g., stir-casting process.

Our formulas for the effective properties of random composites are derived as the mathematical expectation of the effective conductivity over the independent and identically distributed (i.i.d.) non-overlapping inclusions. Even formulas obtained for uniformly distributed non-overlapping balls are not universal, because the effective conductivity depends on the protocol of computer simulations or experimental stirring, meaning that the very notion of randomness is non-universal (Torquato, 2002, Kurtyka and Rylko, 2013, Rylko, 2014, Gluzman et al., 2017).

Some famous formulas turn out to be questionable, in our opinion. The example, why various not rigorous, popular approaches can be questioned, is given in Chapter 6 based on the paper by Mityushev and Nawalaniec (2019). It is demonstrated that the classical Jeffrey formula contains wrong f^2 term. See Chapter 6, where the terms f^2 and f^3 are written explicitly! In particular, we demonstrate that the f^3 term depends on the deterministic and random locations of inclusions. A novel expansion for the random composite with superconducting (perfect conducting) inclusions is obtained, see (6.92) on page 226. It leads to a proper estimate for the critical index for superconductivity. The finding seems to justify the whole body of work on the short series for effective conductivity, and give a physical meaning to the series as a valuable source of estimating critical index $\mathbf{s}$.

Piotr Drygaś
Simon Gluzman
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Kraków, April 2019

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Nomenclature

Geometry

a_k	stands for center (complex coordinate) of the disk D_k
$\mathbf{a}_k$	stands for center of the sphere D_k
BCC	means body-centered cubic lattice
D	stands for a domain in $\mathbb{R}^2$ or in $\mathbb{R}^3$ or stands for circular multiply connected domain
D_k	stands for simply connected domain (inclusion) in $\mathbb{R}^2$ and in $\mathbb{R}^3$ or stands for circular inclusion in $\mathbb{R}^2$ and ball in $\mathbb{R}^3$
∂D	stands for boundary of D
$E_k(z)$	stands for Eisenstein function of order k
$E_m^{(j)}(z)$	stands for Eisenstein–Natanson–Filshtinsky functions
$e_{m_1,m_2,m_3,...,m_n}$	stands for structural sum of the multi-order $\mathbf{m} = (m_1, \ldots, m_n)$ based on the Eisenstein functions
$e^{f_0,f_1,f_2,...,f_n}_{p_1,p_2,p_3,...,p_n}$	stands for structural sum of poly-disperse composite
$e^{(\mathbf{j})}_{\mathbf{n}} \equiv e^{(j_1,...,j_q)(l_1,...,l_q)}_{n_1,...,n_q}$	stands for the elastic structural sum based on the Eisenstein–Natanzon functions
f	stands for volume fraction (concentration) of inclusions
FCC	means face-centered cubic lattice
HCP	means hexagonal close-packed lattice
$\mathbf{n} = (n_1, n_2)$	normal vector to a smooth oriented curve L
$n = n_1 + in_2$	complex form of the normal vector $\mathbf{n} = (n_1, n_2)$
$\mathbb{R}^d$	stands for the Euclidean space
$\mathbf{s} = (-n_2, n_1)$	tangent vector
SC	means simple cubic lattice
S_m	stands for Eisenstein–Rayleigh lattice sums
$S_p^{(q)}$	stands for Natanzon–Filshtinsky lattice sums
$\mathbb{U}$	stands for unit disk on plane
ω_1 and ω_2	stand for the fundamental translation vectors on the complex plane

Conductivity

K	stands for permeability
s	stands for the critical index for superconductivity
t	stands for the critical index for conductivity
$\varrho = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$	stands for contrast parameter between media with the conductivities σ^+ and σ^-; for two-phase composites $\varrho = \frac{\sigma - 1}{\sigma + 1}$
$\sigma(\mathbf{x})$	stands for scalar local conductivity
σ_k	is used for conductivity of the kth inclusion
σ	is used for conductivity of inclusions of two-phase composites when the conductivity of matrix is normalized to unity
$\boldsymbol{\sigma}_e$	stands for effective conductivity tensor
σ_e	stands for scalar effective conductivity of the macroscopically isotropic composites when the conductivity of matrix is normalized to unity
σ_e^{ij}	stands for components of the effective conductivity tensor

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Danube. The Rhine flows towards Holland and England, two markets that have been well established for upwards of three hundred years, and ready to pay a high price for all the river brings them. The Danube flows towards the Black Sea, where the population is exceedingly poor, and can scarcely afford to purchase what we should call here the necessaries of life. The produce of Hungary, even live cattle, is taken westward by rail to London. The transport by water is too long. Secondly, coal, the indispensable fuel of all modern industry, is cheaper on the Rhine than anywhere else. And thirdly, the Rhine, ever since the Roman conquest and at the earliest period of the Middle Ages, has been a centre of civilization, whereas that portion of the Danube the most valuable for traffic was, until yesterday, in the hands of the Turks.

At the Amstett Station I purchased the Vienna *Neue Freie Presse*, which is, I think, with the *Pester Lloyd*, the best edited and the pleasantest paper to read in the German language. The *Kölnische Zeitung* is exceedingly well-informed, and the *Allgemeine Zeitung* is also as complete and interesting as possible; but it is a terrible pell-mell of subjects, a dreadful muddle, where, for instance, many little paragraphs from France or Paris are disseminated haphazard in the six sheets. I would rather read three *Times'* than one *Kölnische*, in spite of the respect with which that paper inspires me. I have scarcely unfolded my *Neue Freie Presse* than I find myself in the very heart of the struggle of nationalities, just as I was sixteen years previously, only that the strife is no longer, as it then was, between Magyars and Germans. The Deak dual compromise created a *modus vivendi*, which is still in force. The dispute is now between Tchecks and Germans on the one hand, and between Magyars and Croatians on the other. The Minister Taaffe has decided to dissolve the Bohemian Parliament and there will be fresh elections. The national and feudal Tchecks banding together will overthrow the Germans, who will no longer possess more than a third of the votes in the Diet. The *Freie Presse* is perfectly disconsolate at this, and foresees the most terrible disasters in consequence: if not the end of the world, at least the upset of the monarchy. On account of these

warnings, the numbers are seized by Government order three or four times a month, even although it be the organ of the Austrian "bourgeoisie." It is Liberal, but very moderate, like the *Débats* and the *Temps* in France. After two or three months have elapsed, the numbers seized are returned to the editor, only fit for the waste-paper basket. These confiscations (for they are, in fact, nothing more nor less, although effected through the Administration) are absolutely contrary to the law, as is proved by the reiterated acquittals. Their constant recurrence reminds one of the worst periods of the French Empire. Applied to a newspaper that defends Austrian interests with so much skill as the *Freie Presse*, they are more than surprising. If my friend, Eugène Pelletan, were aware of this he would no longer claim for France "liberty as in Austria," for which saying he suffered at the time three months' imprisonment. It is said that the influence of the Tchecks dictates these confiscations, and this alone is sufficient to show the violence of the enmity between the races. The Viennese with whom I travel declare that this enmity is far less bitter than it was fifteen years ago. At that period, I tell them, I travelled across the country without meeting a single Austrian. I met with Magyars, Croatians, Saxons, Tchecks, Tyrolians, Poles, Ruthenians, Dalmatians, but never with Austrians. The common country was ignored, the race was all in all. At the present day, my fellow-travellers tell me this is very much subdued. You will find plenty of excellent Austrians, they say, to-day amongst the Magyars, and to-morrow amongst the Tchecks.

The reader will permit a short digression here touching this nationality question. You meet with it everywhere in the dual Empire. It is the great preoccupation of the present, and it will be in fact the chief agent in determining the future of the population of the banks of the Danube and the Balkan peninsula. You Englishmen cannot well understand the full force of this feeling which is so strong in Eastern countries. England is for you your country, for which you live and for which, if needs, you die. This love of country is a religion which survives even when all other faith or religion has ceased to exist. It is the same in France. M. Thiers who, as a rule, so

thoroughly grasped situations, never realized the immense force of these aspirations of races, which completely rearranged, before his eyes, the map of Europe on the nationality footing. Cavour and Bismarck were, however, well aware of this, and knew how to take advantage of this sentiment, in creating the unity of Italy and of Germany.

One evening, Jules Simon took me to call on M. Thiers, in rue St. Honoré, who asked me to explain the Flemish movement in Belgium. I did so, and he seemed to consider the question as most unimportant, quite childish in fact, and very much behind the age. He was at once both right and wrong. He was right because true union is one of minds, not of blood. Christ's saying is here admirably applicable: "Whosoever shall do the will of God the same is my brother and sister and mother" (St. Mark iii. 35).

I grant that mixed nationalities which, without consideration of diversity of language and race, rest, as in Switzerland, on an identity of historical reminiscences, of civilization and liberty, are of a superior order; they are types and forerunners of the final fusion when all mankind will be but one great family, or rather a federation. But M. Thiers, being idealistic, like a true son of the French Revolution, was wrong in not taking into account things as they actually are, and the exigencies of the transitory situation.

This awakening of nationalities is the inevitable outcome of the development of democracy, of the press, and of literary culture. An autocrat may govern twenty different peoples without in the least troubling himself as to their language or race; but if once assemblies be introduced, everything is changed. Speech governs. Then what language is to be spoken? That of the people of course. Will you educate the young? It must be done in their mother tongue. Is justice to be administered? You cannot judge a man in a foreign language. You wish to represent him in Parliament and ask for his votes; the least he can claim in return is that he may understand what you say. And thus by degrees the language of the multitude gains ground and is adopted in Parliament, law-courts, and schools

of every degree. In Finland, for instance, the struggle is between the Swedes, who form the well-to-do classes and live in the towns on the coast, and the rural population who are Finns. When visiting the country with the son of the eminent linguist, Castrén, who died while in Asia seeking out the origin of the Finn language, I found that the latter was more spoken than Swedish, even in the suburbs of large towns such as Abö and Helsingfors. All official inscriptions are in the two languages. The instruction in the communal schools is almost entirely in the Finn tongue. There are Finn gymnasiums, and even at the University, lectures in this language. There is also a national theatre, where I heard "Martha" sung in Finn. In Gallicia, Polish has completely replaced German; but the Ruthenians have also put in a claim for their idiom. In Bohemia the Tcheck dialect triumphs so completely that German is in danger of being wholly cast aside. At the opening of the Bohemian Diet, the Governor made a speech in Tcheck and one in German. At Prague a Tcheck University has recently been opened next to the German one. The clergy, the feudals, and the population are strongly in favor of this national movement. The Archbishop of Prague, the Prince of Schwarzenberg, although himself a German, appoints none but Tcheck priests, even in the North of Bohemia where Germans dominate.

It is certain that in countries where two races are thus intermingled, this growing feeling must occasion endless dissensions, and almost insurmountable difficulties. It is a disadvantage to speak the idiom of a small number, for it is a cause of isolation. It would certainly be far better if but three or four languages were spoken in Europe, and better still if but one were generally adopted; but, until this acme of unity be attained, every free people called upon to establish self-government, will claim rights for its mother tongue, and will try to unite itself with those who speak it, unless the nation be already fully satisfied with its mixed but historical nationality like Switzerland and Belgium. Austria and the Balkan peninsula are now agitated with these claims for the use of the national tongue, and with aspirations for the formation of States based on the ethnic groups.

As we near Vienna the train runs through the most lovely country. A succession of small valleys, with little streamlets rippling through them, and on either side green lawns between the hills covered with woods, chiefly firs and oaks. One might imagine oneself in Styria or in Upper Bavaria. Soon, however, houses make their appearance, often charming châlets buried in creeping plants, "Gloire de Dijon" roses, or jessamine and clematis. These become more and more frequent, and, near the suburban stations, there are quite little hamlets of villas. I know of no capital with such beautiful suburbs, save perhaps Stockholm. Nothing could be more delightful than Baden, Möoling, Brühl, Schönbrun, and all those little rustic nooks south of Vienna, on the road to the Sömering.—*Contemporary Review.*

ANCIENT ORGANS OF PUBLIC OPINION.[56]

BY PROF. R. C. JEBB.

During several weeks in the early part of this year, the attention of the English public was fixed with intense anxiety on the fortunes of one man, who had undertaken a perilous mission in the service of his country. When the Egyptian difficulty was at its worst, General Gordon had started for Khartoum, to aid the Government, by his personal influence, in the policy of rescuing the garrisons and retiring from the Soudan. The journey, while it reflected fresh honor on him, necessarily imposed a grave responsibility on those who had sanctioned it. Any moment might bring the news of his death. If such news came, it was generally thought and said, the Ministry would fall. In a country with the temperament of England, the mere existence of such a belief set one thinking. A year ago, Gordon's name, though familiar to the well-informed classes, would not have acted like a spell on the nation. But a popular biography of him which had appeared had given occasion for much writing in the newspapers. A short time had sufficed to make the broad facts of his career known throughout the length and breadth of the land. People knew that he had welded a loose Chinese rabble into an army which saved the reigning dynasty of China; that, alone of Christians, he is named in the prayers of Mecca; that he does not care for personal rewards; that he is fearless of death; and that he trusts in God. To impress these facts on the popular imagination had been the work of a few weeks; to concentrate the force of popular opinion, if he had been sacrificed, would have been the work of a few hours. Seldom, perhaps, has anything illustrated more vividly that great and distinctive condition of modern existence in free countries,—the

double power wielded by the newspaper press, at once as the ubiquitous instructor and as the rapid interpreter of a national mind. It was natural at such a time, for one whose pursuits suggested the comparison, to look from the modern to the ancient world, and to attempt some estimate of the interval which separates them in this striking and important respect. In the ancient civilisations, were there any agencies which exercised a power analogous in kind, though not comparable in degree, to that of the modern press? To begin with, we feel at once that the despotic monarchies of the ancient East will not detain us long. For them, national opinion normally meant the opinion of the king. We know the general manner of record which is found graven on stone, in connection with the images or symbols of those monarchs. As doctors seem still to differ a good deal about the precise translation of so many of those texts, it might be rash to quote any, but this is the sort of style which seems to prevail among the royal authors: "He came up with chariots. He said that he was my first cousin. He lied. I impaled him. I am Artakhshatrá. I flayed his uncles, his brothers, and his cousins. I am the king, the son of Daryavush. I crucified two thousand of the principal inhabitants. I am the shining one, the great and the good." From the monarchical East, we turn with more curiosity to Greece and Rome. There, at least, there was a life of public opinion. Apart from institutions, which are crystallised opinion, were there any living, non-official voices in which this public opinion could be heard?

The Homeric poems are not only the oldest monuments of Greek literature, but also the earliest documents of the Greek race. Out of the twilight of the prehistoric past, a new people, a new type of mind, are suddenly disclosed in a medium of pellucid clearness. Like Athene springing adult and full-armed from the head of Zeus, this new race, when Homer reveals it, has already attained to a mature consciousness of itself, and is already equipped with the aptitudes which are to distinguish it throughout its later history. The genius of the Homeric Greek has essentially the same traits which recur in the ripest age of the Greek republics,—even as Achilles and Ulysses are personal ideals which never lost their hold on the nation. This very

fact points the contrast between two aspects of Homeric life—the political, and the social. In Homeric politics, public opinion has no proper place. The king, with his council of nobles and elders, can alone originate or discuss measures. The popular assembly has no active existence. But the framework of Homeric monarchy contains a social life in which public opinion is constantly alert. Its activity, indeed, could scarcely be greater under the freest form of government. And we see that this activity has its spring in distinctive and permanent attributes of the Hellenic race. It arises from quickness of perception and readiness of speech. The Homeric Greek feels keenly, observes shrewdly, and hastens to communicate his thoughts. An undertone of popular comment pervades the Homeric poems, and is rendered more impressive by the dramatic form in which it is usually couched. The average man, who represents public feeling, is expressed by the Greek indefinite pronoun, τις. "Thus would a man speak, with a glance at his neighbor," is the regular Homeric formula. We hear opinion in the making. This spokesman of popular sentiment is constantly introduced at critical moments: for the sake of brevity we may call him by his Greek name *Tis*. When the fight is raging over the corpse of Patroclus, *Tis* remarks to his friends that they will be disgraced for ever if they allow the Trojans to carry off the body;—better die on the spot. Hector, in proposing a truce to Ajax, suggests that they should exchange gifts, and imagines what *Tis* will say: *Tis* will approve of it as a graceful courtesy between chivalrous opponents. Menelaus considers that another hero, Antilochus, has beaten him in a chariot race by unfair means; but thinks it necessary to take precautions against *Tis* imagining that he has brought this complaint in the hope of prevailing by the influence of his rank. This is perhaps one of the most remarkable Homeric compliments to the penetration and to the influence of *Tis*. When the sounds of music and dancing, as at a marriage feast, are heard in the house of Odysseus in Ithaca, *Tis* is listening outside; and he blamed Penelope for her fancied hardness of heart, "because she had not had the courage to keep the great house of her gentle lord steadfastly till he should come home." *Tis* is not always the mouthpiece of such elevated sentiments. With a frank

truth to life and nature, Homer depicts *Tis* as indulging in an ignoble joy by stabbing the corpse of his once-dreaded foe, Hector, and remarking that he is safer to handle now than when he was burning the ships. In the *Odyssey*, when the maiden Nausicaa is conducting Odysseus to the city of her father Alcinous, we catch glimpses of a *Tis* who nearly approaches the character of Mrs. Grundy, with an element of spiteful gossip added. The fidelity with which *Tis* reflects public opinion is further seen in the circumstance that his solicitude for the rights of man is not strong enough to counteract his natural disposition to exalt over the fallen. Thersites was a commoner who presumed to speak his mind among his betters,—when one of them, Odysseus, dealt him a smart blow on the back, and caused him to resume his seat in tears. *Tis* laughed for joy, saying in effect that it served Thersites right, and that he probably would not do it again. The Tory sentiment of this passage makes it appropriate to quote the version of it by the late Lord Derby:—

"The Greeks, despite their anger, laughed aloud,
And one to other said, 'Good faith, of all
The many works Ulysses well hath done,
Wise in the council, foremost in the fight,
He ne'er hath done a better, than when now
He makes this scurril babbler hold his peace.
Methinks his headstrong spirit will not soon
Lead him again to vilify the kings.'"

Here it might be said that *Tis* figures as the earliest authentic example of a being whose existence has sometimes been doubted by British anthropologists, the Conservative working-man. But, if we would be just to *Tis* in his larger Homeric aspects, we must allow that his sympathies are usually generous, and his utterances often edifying. As to the feeling with which *Tis* was regarded, Homer has a word for it which is hard to translate: he calls it *aidos*. This *aidos*—the sense of reverence or shame—is always relative to a standard of public opinion, *i.e.* to the opinion formed by the collective sayings of *Tis*; as, on the other hand, the listening to an inner voice, the obedience to what we call a moral sense, is Homerically called *nemesis*. And just as *Tis* is sometimes merely the voice of smug respectability, so *aidos* is sometimes conventional in a low way. When Diomedes is going by night to spy out the Trojan camp, several heroes offer to go with him, but only *one* can be chosen. Agamemnon tells him that he must not yield to *aidos*, and take the man of highest station rather than the man of highest merit: where *aidos* appears as in direct conflict with *nemesis*. But more often these two principles are found acting in harmony,—recommending the same course of conduct from two different points of view. There is a signal example of this in the *Odyssey*, which is also noteworthy on another ground, viz., as the only episode in the Homeric poems which involves a direct and formal appeal from established right of might to the corrective agency of public opinion. The suitors of Penelope have intruded themselves into the house of her absent

lord, and are wasting his substance by riotous living. Her son Telemachus convenes the men of Ithaca in public assembly, and calls on them to stop this cruel wrong. He appeals to *nemesis*, to *aidos*, and to fear of the gods. "Resent it in your own hearts; and have regard to others, neighboring folk who dwell around,—and tremble ye at the wrath of the gods." The appeal fails. The public opinion exists, but it has not the power, or the courage, to act.

After the age which gave birth to the great epics, an interval elapses before we again catch the distinct echoes of a popular voice. Our Homeric friend *Tis* is silent. Or, rather, to be more exact, *Tis* ceases to speak in his old character, as the nameless representative of the multitude, and begins to speak in a new quality. The individual mind now commences to express itself in forms of poetry which are essentially personal, interpreting the belief and feelings of the poet himself. *Tis* emerges from the dim crowd, and appears as Tyrtaeus, summoning the Spartans, in stirring elegy, to hear *his* counsels; or as Sappho, uttering *her* passion in immortal lyrics; or as Pindar, weaving *his* thoughts into those magnificent odes which glorify the heroes and the athletes of Greece. It is a capital distinction of classical Greek literature that, when its history is viewed as a whole, we do not find it falling into a series of artificial chapters, determined by imitation of models which were in fashion at this or that epoch. Greek literature is original, not derivative; we trace in it the course of a natural growth; we hear in it the spontaneous utterance of Greek life from generation to generation. The place of Pindar in this development has one aspect of peculiar interest. There is a sense in which he may be said to stand midway between Homeric epos and Athenian drama.[57] His poetical activity belongs to the years which immediately preceded and followed the invasions of Greece by the hosts of Persia. A great danger had drawn the members of the Hellenic family closer together; a signal deliverance had left them animated by the memory of deeds which seemed to attest the legends of Agamemnon and Achilles; warmed by a more vivid faith in those gods who had been present with them through the time of trial; comforted by a new stability of freedom; cheered by a sense of

Hellenic energies which could expand securely from the Danube to the Nile, from the Euxine to the Atlantic; exalted in thought and fancy by the desire to embody their joy and hope in the most beautiful forms which language and music, marble, ivory, and gold could furnish for the honor of the gods, and for the delight of men who, through the heroes, claimed a divine descent. The Greek mind, stirred to its centre by the victorious efforts which had repelled the barbarian, could no longer be satisfied by epic narratives of the past. It longed to see the heroes moving; to hear them speaking; to throw back upon their world the vivifying light of contemporary reflection. In a word, the spirit of drama had descended upon Hellas; and already it breathes in Pindar, the poet of the games. Olympia, with its temples, its statues, and its living athletes, corresponded to the essence of Greek drama—action idealised by art and consecrated by religion. Pindar, the last of the great lyric poets, is the lyric exponent of an impulse which received mature expression from Aeschylus, Sophocles, and Euripides.

The community which Athenian drama addressed was precisely in the mood which best enables a dramatist to exert political and moral force. There was much in its temper that might remind us of Elizabethan England; but I would venture to illustrate it here by words borrowed from the England of a later time. The greatest plea in the English language for the liberty of the press—or perhaps we should rather say, for the freedom of the mind—belongs to the close of that year which saw the hopes of the Parliamentarians, in their struggle with the Royalists, raised to an assurance of final success by the crushing defeat of Rupert. An enthusiastic confidence in the large destinies opening before the English people already fired the mind of the poet who was to end his days, like Samson

> "Eyeless in Gaza, at the mill with slaves,
> Himself in bonds under Philistian yoke."

Then, in 1644, Milton, thinking of the victory of Marston Moor, was rather like Aeschylus raising his dramatic paean for the victory

of Salamis; and the glowing language in which he describes the new alertness of his country's spirit might fitly be applied to the Athens for which the great dramatists wrote. "As in a body, when the blood is fresh, the spirits pure and vigorous not only to vital but to rational faculties and those in the acutest and the pertest operations of wit and suttlety, it argues in what good plight and constitution the body is, so when the cherfulnesse of the people is so sprightly up, as that it has not only wherewith to guard well its own freedom and safety but to spare, and to bestow upon the solidest and sublimest points of controversie and new invention, it betok'ns us not degenerated, nor drooping to a fatall decay, but casting off the old and wrincl'd skin of corruption to outlive these pangs and wax young again, entring the glorious waies of Truth and prosperous vertue destin'd to become great and honourable in these latter ages. Methinks I see in my mind a noble and puissant Nation rousing herself like a strong man after sleep, and shaking her invincible locks. Methinks I see her as an Eagle muing her mighty youth, and kindling her undazl'd eyes as the full mid-day beam, purging and unscaling her long abused sight at the fountain it self of heav'nly radiance."

In estimating the influence of Athenian drama on public opinion, we must, first of all, remember the fact which makes the essential difference between the position of the dramatist—viewed in this light—and that of the epic poet. The epic poet gave expression to a mass of popular belief and feeling in an age when they had as yet no direct organ of utterance. But in the Athens of the dramatists the popular assembly was the constitutional organ of public opinion. Every Athenian citizen was, as such, a member of that assembly. The influence of the Athenian dramatist was thus so far analogous to that of the modern journalist, that it was brought to bear on men capable of giving practical effect to their sentiments. A newspaper publishes an article intended to influence the voters in a parliamentary division, or the constituents whom they represent. An Athenian dramatist had for his hearers, in the theatre of Dionysus, many thousands of the men who, the next day might be called upon to decide a question of policy in the assembly, or to try, in a law-

court, one of those cases in which the properly legal issues were often involved with considerations of a social or moral kind. Even Tragedy, in its loftiest and severest form, might be the instrument, in a skilful hand, of inculcating views or tendencies which the poet advocated—nay, even of urging or opposing a particular measure. Thus, in his *Furies*, Aeschylus finds occasion to encourage his fellow-citizens in their claim to a disputed possession in the Troad, and utters a powerful protest against the proposal to curtail the powers of the Areopagus. He becomes, for the moment, the mouthpiece of a party opposed to such reform. In verses like the following, every one can recognize a ring as directly political as that of any leading article or pamphlet. "In this place"—says the Athene of Aeschylus—that is, on the hill of Ares, the seat of the court menaced with reform—

> "Awe kin to dread shall stay the citizens
> From sinning in the darkness or the light,
> While their own voices do not change the laws ...
> Between unruliness and rule by one
> I bid my people reverence a mean,
> Not banish all things fearful from the State.
> For, with no fear before him, who is just?
> In such a righteous dread, in such an awe,
> Ye shall possess a bulwark of the land,
> A safeguard of the city, not possess'd
> By Scythia or the places of the south.
> This court, majestic, incorruptible,
> Instant in anger, over those who sleep
> The sleepless watcher of my land, I set."

Again, there are at least two tragedies of Euripides—the *Heracleidae* and the *Supplices*—in which the strain of allusion to the politics of the Peloponnesian War is unmistakable. It is needless to dwell on the larger sense in which Euripides everywhere makes drama the vehicle of teachings—political, social, moral—which could

nowhere have received such effective publicity as in the theatre. Nowadays, they would have been found in the pages of a newspaper or a magazine accepted as the organ of a party or a school. In the days of Voltaire, journalism, as free countries now understand it, had no more existence than in the days of Euripides; and, as a recent historian of French literature remarks, it has been thought that the tragedies of Voltaire owed their popularity chiefly to the adroit manner in which the author made them opportunities for insinuating the popular opinions of the time.[58] We must not forget that peculiar feature of Greek drama, the Chorus, who may be regarded as a lineal descendant of the Homeric *Tis*. The interest of the Chorus, in this connection, does not depend so much on the maxims that it uttered as on the fact that it constituted a visible link between the audience and the drama, bringing the average spectator into easier sympathy with the action, and thereby predisposing him to seize any significance which it might have for the life of the day. I have so far dwelt on this aspect of Athenian Tragedy, because we might be rather apt to regard it as a form of art altogether detached from contemporary interests, and to overlook the powerful influence —not the less powerful because usually indirect—which it must undoubtedly have exercised in expressing and moulding public sentiment.

But we must now turn to that other form of Athenian drama in which the resemblance to the power of the modern press is much more direct and striking—that which is known as the Old Comedy of Athens. Mr. Browning, in his *Apology of Aristophanes*, makes the great comic poet indicate the narrow limits to the influence of Tragedy on opinion. The passage is witty; and though, as I venture to think, it considerably underrates the effect of Tragedy in this direction, at least it well marks the contrast between the modes in which the two forms of drama wrought. When we think of the analogy between Aristophanes and the modern political journalist, one of the first things that strikes us is the high and earnest view which Aristophanes took of his own calling. He had gone through every stage of a laborious training before he presumed to come

before the Athenian public. He had seen his predecessors fail, or fall from favor. So in the *Peace*, he claims that he has banished the old vulgar tomfoolery from the stage, and raised his art "like an edifice stately and grand." He saw clearly the enormous force which this literary engine, Comedy, might wield. He resolved that, in his hands, it should be directed to more elevated and more important aims. Instead of merely continuing the traditions of scurrilous buffoonery, in which virulent personality was often the only point, he would bring his wit to bear on larger aspects of politics and society.

But, while his wit and style had the stamp of bold originality, Aristophanes is not the champion of original ideas. Rather his position depends essentially on the fact that he represents a large body of commonplace public opinion. He represents the great "stupid party," to use a name which the English Tories have borne not without pride, and glories to represent it; the stupid party, who are not wiser than their forefathers; who fail to understand how the tongue can swear, and the soul remain unsworn; who sigh for the old days when the plain seafaring citizen knew only to ask for his barley-cake, and to cry "pull away;" who believe in the old-fashioned virtues, and worship the ancient gods. He describes himself as the champion of the people, doing battle for them, like a second Hercules, against superhuman monsters. The demagogues, whom he lashes, try to represent him as slandering the country to foreigners; but he is the country's best friend. Athenians are hasty, fickle and vain. He has taught them not to be gulled by flattery. He has taught them to respect the rights and redress the wrong of their subjects. The envoys who bring the tribute from the island long to see him. The King of Persia, he says, asked two questions about the combatants in the Peloponnesian War. Which side had the strongest navy? and which side had Aristophanes? Thirlwall, in his *History of Greece*, denies that Aristophanic Comedy produced any serious effect. "We have no reason," he says, "to believe that it ever turned the course of public affairs, or determined the bias of the public mind, or even that it considerably affected the credit and fortunes of an obnoxious individual." Grote's opinion is much the same, except

that he is disposed to credit Comedy with a greater influence on the reputations of particular men. The question is much of the same nature as might be raised concerning the precise effect of political writing in newspapers, or of literary reviews. The effect is one which it is impossible to measure accurately, but which may nevertheless be both wide and deep.

In the first place, we must dismiss the notion that Comedy could make no serious impression because the occasion was a sportive festival. The feelings of Athenians at Comedy were not merely those of a modern audience at a burlesque or a pantomime. Comedy, like Tragedy, was still the worship of Dionysus. Precisely in those comedies which most daringly ridicule the gods—such as the *Birds* and the *Frogs*—we find also serious expressions of a religious sense, illustrating what might be called the principle of compensatory reverence. Again, the power of the Old Athenian Comedy is not to be gauged by any influence which it exercised, or sought, over special situations or definite projects. Indeed, it rarely attempted this. Almost the only extant instance occurs in the *Frogs* of Aristophanes, where he urges that a general amnesty should be granted to all citizens who had been implicated in the Revolution of the Four Hundred. In such a sense, it may be granted, Comedy might do little; but its real power operated in a totally different way. When a large body of people has common opinions or feelings, these are intensified in each individual by the demonstration that so many others share them. A public meeting tends in itself to quicken enthusiasm for a party or a cause, be the oratory never so flat and the sentiments never so trite. Aristophanes gave the most brilliant expression to a whole range of thought and feeling with which thousands of minds were in general sympathy. Can it be doubted that he contributed powerfully to strengthen the prejudice against everything that he regarded as dangerous innovation? Or, again, can it be doubted that he did much to give his fellow-citizens a more vivid insight into the arts of unscrupulous demagogues? The cajolers of the people, as depicted in the comedy of the *Knights*, are drawn in strong colors, but with fine strokes also: while the character of

Demus, the People—their supposed dupe—is drawn with a tact which no satirist or political journalist has ever surpassed. If I have to stake the political power of Aristophanes on the evidence of one short passage, it should be that dialogue in which the Knights deplore the dotage of Demus, and Demus tells them that, while he seems to doze, he always has one eye open (vv. 1111-1150).

When a change of Ministry occurs in England, no one would undertake to say exactly what share in that result is attributable to journalistic repetition and suggestion—to the cumulative impression wrought on the public mind, through weeks, months, and years, by the Conservative or the Liberal press. And he would be a bold man who presumed to say how little or how much the Old Comedy may have to do with the phenomena of oligarchic reaction in the latter part of the Peloponnesian War, or with the stimulation of all those sentiments which have their record in the death of Socrates. The confused travesty of Socrates in the *Clouds* corresponds, in its general features, with the confused prepossessions of which he was afterwards the victim. In this case, as in others, Comedy was not the origin, but the organ, of a popular opinion. It did not create the prepossessions; but it strengthened them by the simple process of reflecting them in an exaggerated form. Briefly, Aristophanic Comedy had many of the characteristics of vehement party journalism, but was directed either against persons, on the one hand, or against general principles and tendencies on the other—not against measures. Its most obvious strength lay in brilliant originality of form; but its political and social effect depended essentially on its representative value. It was the great ancient analogue of journalism which seems to lead opinion by skilfully mirroring it—unsparing in attack, masterly in all the sources of style, but careful, where positive propositions are concerned, to keep within the limits of safe and accepted generalities.

Just as the Old Comedy was losing its freedom of utterance, a new agency began to appear, which invites comparison with journalism of a calmer and more thoughtful type. Rhetoric, of which we already feel the presence in Athenian drama, had now become a

developed art. Skill analogous to that of the modern journalist was often required, for purposes of speaking, by the citizen of a Greek republic.[59] He might desire to urge his views in a public assembly where the standard of speaking was high and the audience critical. He might be compelled to defend his fortunes, or even his life, before a popular jury of many hundreds, when the result would depend in no small measure on oratorical dexterity. Already a class of men existed who composed speeches for private persons to deliver in law-courts. The new art was naturally enlisted in the service of any party politics. A skilful writer now felt that there was a way of producing an effect which would be less transient than that of a speech in the assembly. From the end of the fifth century B.C. we begin to meet with a species of composition which may best be described as a political pamphlet.

The paper on the Athenian polity, which has come down under Xenophon's name, is an aristocratic manifesto against the democracy, which might have appeared in an ancient *Quarterly Review*. The paper on the *Revenues of Athens*, belonging to the middle of the fourth century B.C., is a similar article in favor of peace and the commercial interests. Many of the extant pieces of the orator Isocrates, in the fourth century B.C., though couched in the form of speeches, were meant to be read, not spoken, and are in reality highly finished political pamphlets. More, perhaps, than any other writer of antiquity, Isocrates resembles a journalist who is deeply impressed with the dignity and responsibility of his calling; who spares no pains to make his work really good; and who has constantly before his mind the feeling that his audience is wider, and his power greater, than if he was actually addressing a public assembly on the same theme. His articles—as we may fitly call them —are usually intended to have a definite effect at a particular moment. He wishes to make Athens and Sparta combine at once in an expedition to Asia. He wishes to strike in with a telling argument for peace at the moment when negotiations are pending between Athens and her allies. He desires to strengthen the hands of the party, at Athens and at Sparta, who refuse to recognize the

restoration of Messene by the power of Thebes. In this last case, we know that a pamphlet on the other side was written by the rhetorician Alcidamas. Here then is an example of literary controversy on contemporary public affairs.

Nor is it merely in regard to the political questions of the day that Isocrates performs the part of a journalist. He deals also with the social life of Athens. He expresses the feeling with which men of the old school observed a deterioration of manners connected, in their views, with the decay of Conservative elements in the democracy. He shows us the throngs of needy citizens, eagerly casting lots outside the law-courts for the privilege of employment as paid jurymen—while at the same time they are hiring mercenary troops to fight their battles abroad. He pictures the lavish display which characterized the festivals of the improvident city—where the amusement of the public had now become a primary art of statesmanship—when men might be seen blazing in gold spangled robes, who had been shivering through the winter in rags. He brings before us the young men of a degenerate Athens—no longer engaged in vigorous exercises of mind and body, in hunting or athletics; no longer crossing the market-place with downcast eyes, or showing marks of deference to their elders—but passing their hours in the society of gamesters and flute-players, or lazily cooling their wine in the fountain by the Ilissus. He is, in brief, a voice of public opinion on all the chief matters which come within the province of the publicist. In order that such a writer should have an influence similar to that of a newspaper, it was enough that copies of his writings should be sufficiently multiplied to leaven the conversation of the market-place and of private society. Every possessor of a copy was a centre from which the ideas would reach the members of his own circle. And there is good evidence that, in the fourth century B.C., the circulation of popular writings throughout the Hellenic world was both wide and rapid. The copying industry, in the Greece of that age, doubtless fell far short of the dimensions to which the labor of cultivated slaves (the *literati*) afterwards raised it at Rome—where we hear of Augustus, for instance, confiscating no

fewer than two thousand copies of a single work—the psuedo-Sibylline books. But it was still amply sufficient to warrant a general comparison, in the sense just defined, between the influence of such a writer as Isocrates, and that of a modern journalist.

We have hitherto spoken only of the written rhetoric, in which the form of a speech was merely a literary fiction, like that adopted —in imitation of Isocrates—by Milton, when he chose to couch his *Areopagitica* in the form of a speech addressed to the Lords and Commons of England. But in passing, we should note that the actually spoken rhetoric of antiquity—especially of Greece—bore a certain analogy to the more elaborate efforts of journalism. This depends on the fact that ancient usage fully recognised, and generally expected, careful premeditation; while the speaker, conscious of the demand for excellence of form, usually aimed at investing his speech with permanent literary value. Demosthenes and Cicero are both witnesses to this: Cicero, doubtless, piqued himself on a faculty of extemporising at need, but probably trusted little to it on great occasions; while with Demosthenes it was the rule, we are told, never to speak without preparation. Take the oration delivered by Lysias at the Olympian festival, where he is exhorting the assembled Greeks to unite against the common foes of Hellas in Sicily and in Persia. Here the orator is essentially an organ of patriotic opinion, and his highly-wrought address is a finished leading-article, for which the author sought the largest publicity.

In turning from Greece to Rome, we are prepared to find literature holding a different relation towards public opinion. The Greek temperament with its quick play of thought and fancy, had an instinctive craving to make the sympathy of thoughts continually felt in words, and to accompany action with a running comment of speech. The Roman, as we find him during Rome's earlier career of conquest, was usually content to feel that his action was in conformity with some principle which he had expressed once for all in an institution or a statute. His respect for authority, and his moral earnestness—in a word his political and social gravity—rendered him independent of the solace which the lively Greek derived from a

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